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Real Time Machine Health Monitoring and Vibrational Analysis using FFT Approach

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Abstract—The most significant role of an industrial machine is its longevity i.e its ability to perform normally and to produce accurate results for extensively long periods of time. To sustain that longevity of the machine, 'Health Monitoring' is required. Health Monitoring is a promoted and very helpful tool for predictive maintenance techniques. When a machine breaks down, the consequences can range from a personal injury to a public disaster. For this reason, early detection, identification, and rectification of machine faults are required to ensure the safe operation of the machine. When the faults begin to develop in a machine, some of the dynamic properties of the machine change, which influences the machine vibration level and spectral vibration properties. Such changes can act as an indicator for early detection and identification of developing faults. Vibrations are majorly found in the rotating shaft. The rotating shaft vibrates extensively due to improper alignments and imperfect bearings. This paper overviews the generalized health monitoring concept for machines and presents the health monitoring of a rotating machine based on Vibration Data Analysis using an enhanced Fast Fourier Transform Approach. Considering the importance of recent trends of the Industrial Internet of Things (IIoT), remote data analysis is implemented using Python, TCP/IP protocol and Hercules server terminal.

Keywords—Machine Health Monitoring, Fast Fourier Transform (FFT), Vibrational Analysis, Industrial Internet of Things (IIoT).

I. INTRODUCTION

With 21st century in hand, significant transformations are taking place in the field of industrialization. The major focus lies on the usage of machines and tools which provide zero-defect manufacturing and requires lesser production time. In order to achieve continuous functioning of any industry, one needs to work on predictive and preventive maintenance of its machines. The contribution of the work presented in this paper consists of a real-time machine health monitoring and vibrational analysis using Fast Fourier Transform (FFT) algorithm.

The Fast Fourier Transform (FFT) analysis is applied to vibration signals obtained from rotating machinery. The machine needs to stay under steady state operating conditions. This analysis is applicable to detect failures on gearboxes, broken-rotor bars and mechanical unbalance in induction motors [1], [2], [3].

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II. DATA ACQUISITION

The first step in order to conduct an experiment or analysis is to acquire the data by careful positioning of the vibration sensor at critical positions on the machine. To obtain data that can help in analyzing the vibration signals from the machine, one needs to place the sensor on the rotating shaft. The data is collected and further sent to the server [4].

III. DATA INTERPRETATION & RESULTS

Under normal operating conditions, when the vibration sensor is attached to the rotating shaft, it can be observed that, a to and fro motion about its mean position, also called as vibration takes place. This data is tracked down to the server using a microcontroller and when FFT analysis is carried out with the help of Python, the response obtained is as shown inFig.1,where the largest peak value is referred to as natural frequency.

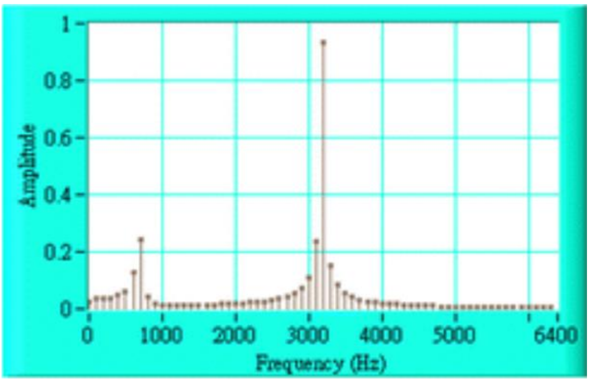

Fig.1 Response of an accurate machine.

When a machine is faulty the accelerometer detects some additional vibrations, which can be plotted in the frequency domain using a Fast Fourier Transform algorithm. The additional peaks apart from natural frequency are the unwanted ones which prove the presence of defects or faults in the machine. These external frequencies can be clearly observed in the response as shown in Fig.2.

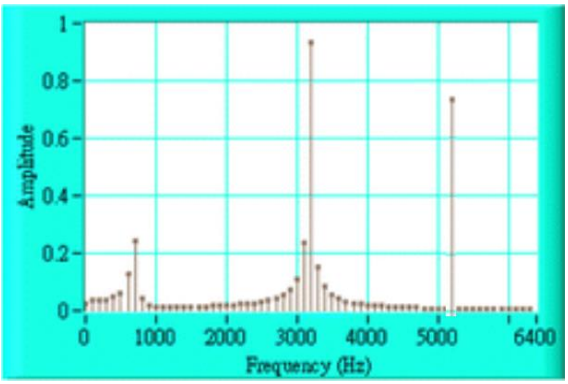

Fig.2 Response of a faulty machine (an external frequency is detected)

IV. FAST FOURIER TRANSFORM APPROACH

Any waveform is a sum of series of sinusoidal waves with varying frequency, amplitude and phase [5]. Vibration analysis can be tested in the frequency domain by examining each frequency component of a waveform. A Discrete Fourier Transform or DFT works on the principle of taking the product of given waveform with sinusoidal waves of varying discrete frequencies and matching the outcomes with each frequency. This turns out to be a lengthy process. Therefore, Fast Fourier Transform or FFT is used as an efficient way to calculate the same result by utilizing the symmetry in sine waves.

From the reference quoted above,

Assumption: Let 'N' be the length of any signal

DFT requires N^2 operations

FFT requires $N*\log_2(N)$ operations

This creates a significant amount of time difference in the execution of both the processes. Thus, FFT is preferred over DFT.

V. TECHNOLOGICAL ADVANCEMENT

With the cusp of Industrial Revolution 4.0 (IR4), industries extensively aim at technological advancement to make them smarter [6]. Introducing the Industrial Internet of Things (IIoT) to achieve remote accessibility is a notable step to improve efficiency and productivity. With the server equipped with end-to-end data from a machine, it can be easily accessed from anywhere at any time through IIoT.

Transmission Control Protocol/Internet Protocol (TCP/IP) protocol is utilized in order to develop a communication platform between a vibration sensor and the server. To accommodate the heterogeneity of devices and applications from various vendors, modern IoT systems have adopted the open standards of TCP/IP protocol suite as a networking solution [7]. It works on the client/server principle in which 2 nodes are required for bidirectional communication. Here, one node is assigned the task of listening and the other node always reaches out to the initial node in order to form a communicating circle. The listener job is assigned to the server and the other node which works on transferring the data is the sensor. The TCP/IP protocol has 4 layers namely,

I. Application
II. Transport
III. Network
IV. Physical layer

Unlike the OSI model which has 7 layers. This protocol functions entirely on two main agendas. Firstly, TCP governs the assembling and reassembling of small packets of information from source to destination. Secondly, IP defines the exact address or location of each packet. It makes sure that each packet reaches the right destination at the right time. A TCP socket server is designed to increase the reliability of the communication system. A full duplex mode is obtained with an add-on feature of controlling the flow of packets or information. It significantly reduces the chances of overrun or overflow.

With the satisfactory functioning of the server, one can monitor the condition of a machine from anywhere using a mobile phone or laptop.

VI. FLOW OF THE PROCESS

A systematic approach towards this preventive maintenance technique follows a sequential order. As depicted in Fig.3 a detailed flowchart highlights the major steps involved in the entire process.

- Vibration sensor or accelerometer (MTN 1186-2) is placed at critical positions of the rotating shaft. It is suitable to place the accelerometer at or near the bearings because the primary defects are observed there. As the vibrations develop in the faulty shaft, the accelerometer generates electric signals which are directly proportional to the acceleration of the shaft [8].

The sensor is further attached to ESP8226. It is a WiFi module equipped with TCP/IP protocol. The TCP socket is designed for remote communication. The data is tracked down to the server for remote access and IIoT implementation.

- Hercules Server Terminal is a freeware serial port terminal used to log data obtained from the server. Once the data is sent to the server, the Hercules Server Terminal is used to log the entire data into a text file. So, the real time data starts accumulating in that text file [9].
- The complete programming is based on Python. The python script firstly extracts the logged data from the text file and then the FFT algorithm is deployed. FFT algorithm analysis is conducted in order to obtain frequency response. If an external peak is detected in the spectrum, the shaft is stated as faulty. The ability of FFT is to clearly indicate the major frequencies which helps in determining the source of any vibration signal [10], [11], [12].

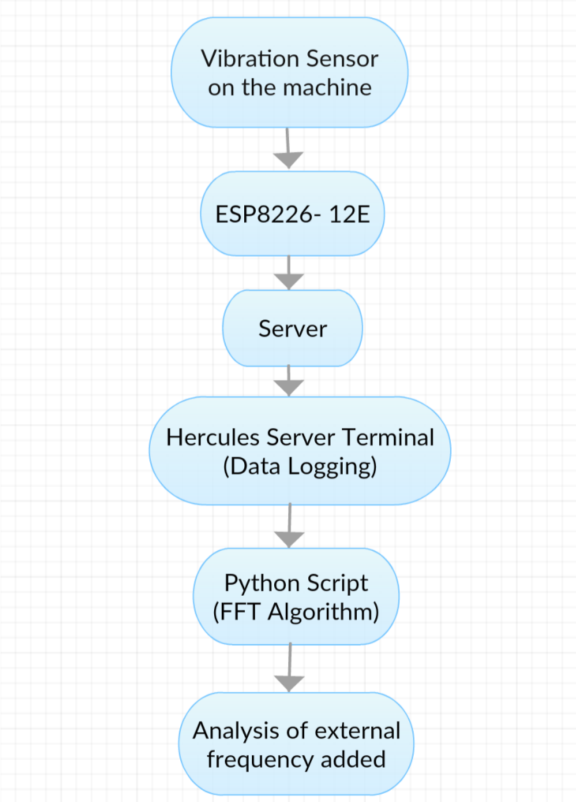

Fig.3 Flowchart

VII. EXPERIMENTAL SETUP

An accelerometer MTN 1186-25, shown in Fig. 4, was used to acquire the continuous vibration data from the rotating shaft of the motor.

Fig.4 Accelerometer (MTN 1186-25)

The accelerometer is connected to the ESP8226 (shown in Fig.5) card which sends the real-time data to the server using TCP/IP protocol.

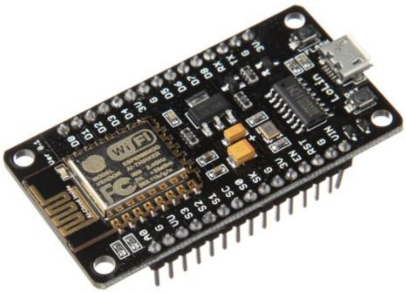

Fig.5 WiFi microchip with TCP/IP stack and microcontroller potential (ESP8226)

The experimental set for the health monitoring of machine is shown in fig. 6. The motor that was chosen for this experiment had a defective rotating shaft. The motor with the misaligned rotating shaft was specifically chosen to see the impact of the hardcore vibrations on Fast Fourier Transform Plot. The motor works on 24V DC with a speed of 0 - 3000 rpm.

Fig.6 Experimental Test Set-Up

The real-time vibration data could be accessed on any computer using the Hercules Server Terminal. This terminal would log the vibration data in the text file completely. The data logged into the text file is fetched by a python script which would convert the real-time vibration data in the frequency domain using a Fast Fourier Transform (FFT) algorithm.

The Python script used the libraries like ‘matplotlib' for plotting the Fast Fourier Transform (FFT), ‘numpy' for matrix calculations and ‘pandas' to retrieve the data from the text file.

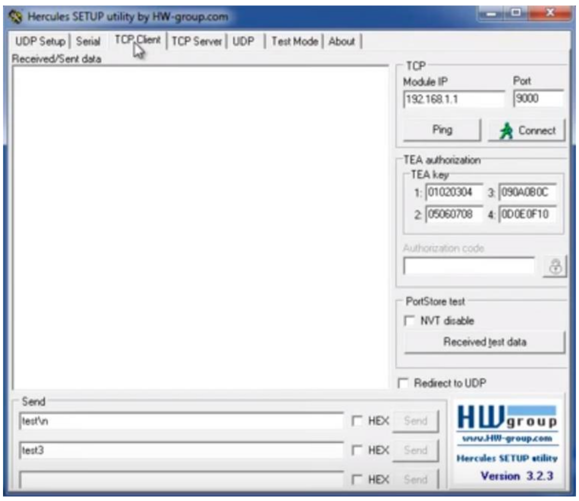

Fig.7 Hercules Server Terminal

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FFT Specifications: [12]

The vibration signal from MTN 1186 -25 sensor is taken as an input to the FFT algorithm which is computed as follows:

Number of samples (N): 2048

Total Sampling (T): 60 ms

Sampling Frequency (Fs): N/T = 34,133 Hz ≃34,000 Hz

While the FFT output spectrum can be calculated as follows:

Maximum Frequency ($Fmax$) = Fs/2= 17,000 Hz

Number of spectral lines= N/2= 1024

Frequency Resolution (dF)= Fs/N= 16.6

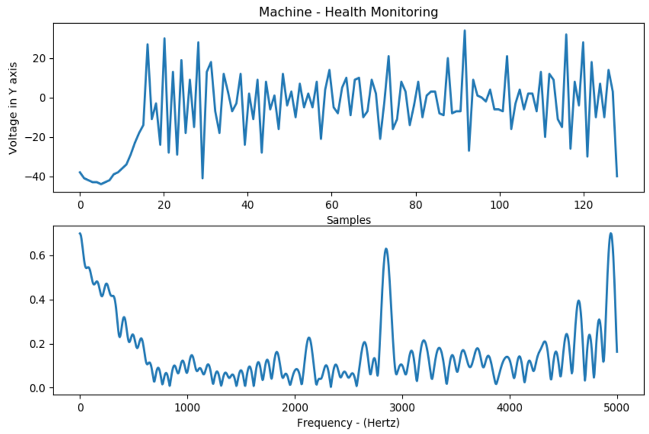

Fig.8 FFT spectrum indicating a fault in the motor.

VIII. OBSERVATIONS

The Fast Fourier transform plot of any industrial machine working smoothly generally has only one peak which basically indicates the natural frequency at which the machine is operating.

Whenever any other peak is formed other than the natural frequency peak in the plot, it implies that there is some defect in the machine. So, in the industries whenever there is an addition of another peak in the Fast Fourier transform plot, an alert is generated so that the defect is analyzed and necessary steps are taken to rectify the faults.

In the experiment performed, it was observed that due to the presence of misaligned shaft in the motor, there was an additional frequency (5000 Hz) generated in the Fast Fourier transform plot apart from the 2950 Hz natural frequency. This additional peak is clearly observed in the FFT plot shown in fig. 8.

IX. CONCLUSION

This paper presents a remote monitoring technique for preventive maintenance of machines in industries. Major faults like rotor imbalance, misalignment of the shaft, bearings, etc. can be monitored using our proposed method which involves the detailed application of Fast Fourier Transform. By introducing the Industrial Internet of Things (IIoT) we put forward an advanced means of information accessibility in the market. Implementation of a vibration analysis program can significantly reduce maintenance cost for a production plant and also enhance plant reliability and safety.

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